Simulation Based Layout Design and Optimization for Assembly Line System

Yang Li, Naihui He, David Z. Zhang

Abstract: **This paper investigates the layout design and optimization for an assembly line system in an industrial case based on the Discrete Event Simulation (DES) technique. The purpose of the simulation system was to build up different layouts of the prepared manufacture system and, especially, to propose a solution designed to decrease the need for workforce and to settle bottlenecks problem in the system. In this study, based on the analysis of the manufacturing process of the typical manufacturing part and the available facilities in the assembly system, three layout designs are proposed based on Straight-line, U-shape and Parallel U-shape patterns respectively. A DES simulation environment by using the software of Witness is the established in line with the machinery data provide by the company as well as the experiential data identified from the literature. The three layout designs are then tested in the simulation environment, whose simulation performances are compared and analyzed in terms of the line balance and production efficiency. The results show that the Parallel U-shape line gives rise to the best solution.**

Key words: **Discrete Event Simulation; Witness modeling; computer simulation; U-shaped layout**

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1. Introduction

Effective factory layout planning is imperative to the cost and time efficiency of manufacturers in a globally competitive environment [1], particularly when manufacturers are required to be agile in order to keep up with varying customer demand and product mix [2]. Well-designed facilities result in efficient materials handling, reduced resource transportation times and decreased production cycle times [3]. In addition, effective layout design of arranging facilities can reduce average manufacturing costs and improve operational performance of manufacturing systems [4].

As an effective technique to improve the performance of manufacturing systems, simulation-based optimization has received great attentions from both academic scholars and industrial practitioners. In fact, for this particular category of systems, discrete event models are usually adopted to reproduce their dynamics.[5] Computer simulation of the material flow in a production system is commonly employed before launching a new production line or to enable a predictive production control.[6] Also, The simulation provided a visual aid that helped to assure that all of the required processes were taken into account. The model provided a graphical representation of the flow of material, indicated WIP levels, and identified blockages. These are features that are easily identifiable through the use of simulation. Therefore, there were very few surprises when the line was installed and operational. [7]

The aim of this paper is to outline the possibilities afforded by the Witness simulation environment for theconstruction of models and the subsequent simulation ofconcrete manufacturing systems. In our workplace forinstance, we have used this environment to verify thefunctionality of suggested designs for the production lines ofthe company; or in the course of designing solutionsdesigned to increase productivity and the discovery

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ofbottlenecks in the production line.

2. Literatures' review

A. *computer simulation of DES in the manufacturing system*

Discrete Event Simulation (DES) is an effective tool to analyze complex manufacturing operations with product and process variability. In addition, DES has advantages for performing analysis to any future scenarios for improved process time and efficiency.[8]

Automotive, electronics and other general production industries have identified simulation modeling as a method to analyze and improve their manufacturing facilities.DES in particular has been widely applied to model and optimize complex manufacturing systems and assembly lines. DES is particularly well suited for modeling manufacturing systems, as DEScan explicitly model the variation within manufacturing systems using probability distributions.[9]At the same time, the reconfiguration of manufacturing and repair facilities can be a disruptive, expensive and time consuming process. This leads to the requirements for virtually modeling the system to assist managers in understanding the effects of proposed changes on their manufacturing systems [10]. Manufacturing facilities are often too complex to be modeled mathematically; this gives rise to the need for Discrete Event Simulation (DES) methods. DES can be used to assist managers in modeling and simulating the performance of their manufacturing systems [11].DES ha sbeen used for many applications in manufacturing environment. Sharda and Akiya [12] used DES to select postponement and make-to-stock policies for different products in a chemical plant. An approach which combines simulation and mathematical modeling for setting order due date in a produce-to-order manufacturing environment was presented in Tunalietal [13]. Mehrai et al. [14] modeled the logistics for production and then optimized parameters for autonomous objects. Wischnewski and Freund [15] presented a solution for modeling transportation systems within a production environment. Alrabghi & Tiwari[16] provided an up-to-date review of simulation optimization for maintenance systems.

B. *The U-shaped layout of manufacturing assembly line*

Flexibility is one of the most crucial criteria of modern manufacturing systems to satisfy customized demands in a cost-effective manner. As mentioned by Miltenburg [17], U-shaped lines (or U-lines shortly) do not only provide the flexibility and efficiency of a proper line design but also increase functionality of workers on the line. Fig.1 provides a schematic depiction of a U-shaped line configuration. Ibrahim Kucukkoc [18] proposed a hybrid line configuration, namely parallel U-shaped assembly line system which is illustrated in Fig.2, with the view tomaximizing resource utilization and decreasing the need for workforce. Two U-shaped lines are located in parallel to each other to establish an assembly environment where operators are multi-skilled and located between two adjacent lines, being able to handle tasks on both of the lines.

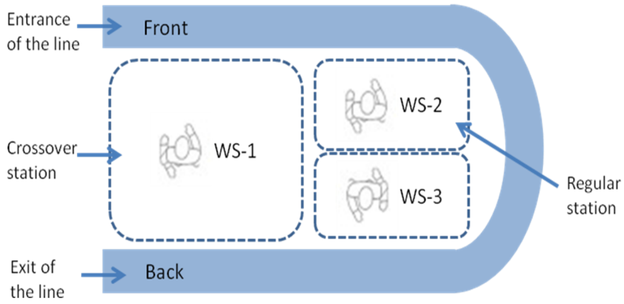

Fig.1 Typical illustration of a U-shaped line configuration

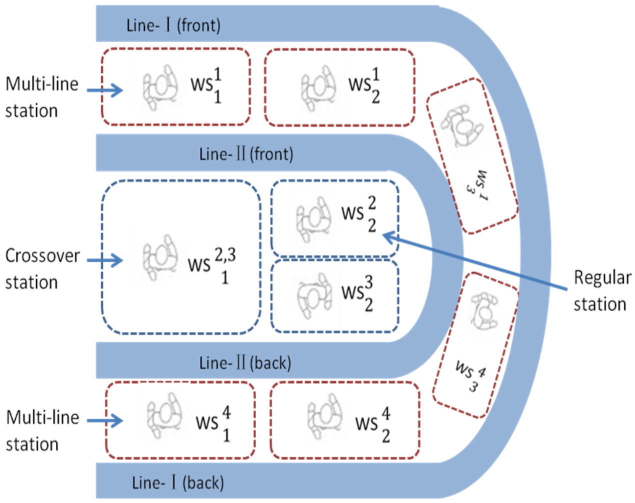

Fig.2 Schematic representation of the proposed parallelU-shaped assembly line system

There are authors who cover the use of simulation for designing U-shaped assembly lines. Wang et al. [19] used a combination of mathematical modeling and simulation in order to analyzea linear walking worker assembly line, i.e. a one-piece flow system. Tiacci[20] described a JAVA-based simulation for model-mix assembly lines including stochastic operation times, parallel stations, a fixed scheduling sequence and buffers between work stations. His simulation procedure is suitable formodeling both straight-line and U-shaped systems. Martinez and Bedia [21] presented a modular program based on the WITNESS simulation procedure, which is used to model a U-shaped assembly system. Baykoç[22] used an adapted heuristic method, which had originally been developed by Arcus[23] under the name of COMSOAL (Computer Method of Sequencing Operations for Assembly Lines).They used the approach to model a U-shaped single-product assembly system for washing machines andanalyze its behavior employing the ARENA simulation procedure. Finally, Eryürük[24] worked with different heuristic methods to re-balance a clothes production line. Afterwards, she simulated the systemsusing the ARENA procedure.

The simulation of the assembly line in the types of the straight layout, the U-shaped layout and the parallel U-shaped layout using WITNESS procedure is processed, and the results of simulation are compared and evaluated together.With the best performance of simulation in the perspective of decrease of the need for workforce and the balanced loading of equipment, parallel U-shaped layout is chosen as the solution for the production line.

3. Description of the Assembly Line

The possibilities of making use of the Witness simulationenvironment are herein presented in the form of simulationstudy that was performed within the framework ofcooperative ventures between our workplace and industrialpartner. To be exact, this was the use of the Witnessenvironment to design and analyze different layouts of a production line in a machinery company. In our study, one typical manufacturing part is chosen from the company, whose process flow is given in Fig.3

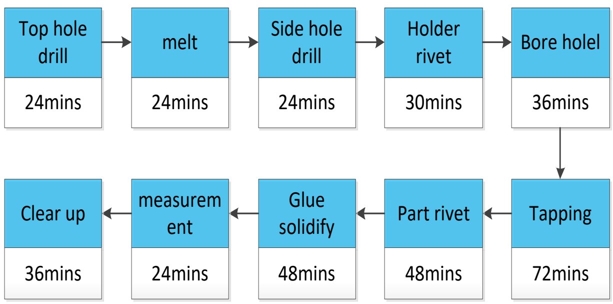

Fig.3 Process flow chart of the part

The manufacturing part has four major types, amongst of which, three have 10 operations and the other one has 9 operations. There are two production lines to make the four types of parts, each of which has 15 machines and is responsible for making two types of part. To clarify, some operations in making the part are processed by two or three machines concurrently in order to balance the average throughput of the entire production process. The simulation environment in our study is designed based on the use of the Witness simulation environment. Witness is the product of the British Lanner Group company and one of the most successful world class environments for the simulation of manufacturing, ancillary service and logistics processes.

To find a layout design solution to decrease the need for workforce and to eliminate bottlenecks in the system, three typical layouts, straight layout, U-shaped layout and parallel U-shaped layout are simulated in the witness environment.

4. Construction of the Model in the Witness Environment

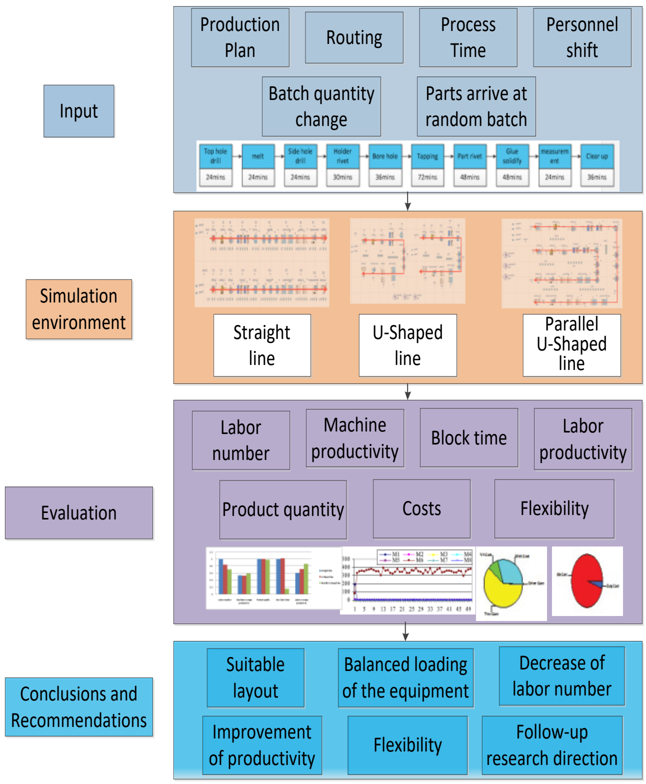

Fig 4 Architectural solution of the simulation

Fig.4 establishes the architectural solution of simulation. The whole architecture contains four steps: input from the reality, simulation in three layouts, simulation data analysis (i.e., evaluation from labor number, productivity, blocks, costs and so on), and conclusions and recommendations to get suitable layout and solve the block problem.

In our simulation environment, all of the machines in the production assembly lines work on a similar principle. The

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operator approaches the machine, positions the incomplete product in its initial starting position, performs the requisite essential steps associated with the individual operations, and instructs the machine to begin operations.

The time measurement unit for the model is in minutes, to meet the requirements in compliance with the provided outputs. The simulation period chosen is seven working days (i.e. two-shift operations). The machine time represents the actual time that each individual machine needs to complete its production operation, which is termed as -cycle time in the simulation model. The operator time is inputted into the model, modified by a randomizing factor based upon a Gauss Curve with a 20 % spread factor.

In this paper, what we discuss is the assembly lines, and the parts putting into the assembly lines are from other plants. The batch quantity of the parts from other plants couldn't keep the plan. The batch quantity is inputted into the model, changed by a randomizing factor based upon a Passion with a 30% spread factor.

5. EVALUATION OF SIMULATION EXPERIMENTS AND RESULTS

The three typical layout patterns identified above, i.e., straight, U-shape and Parallel, are simulated individually in the simulation environment established in our study. However, due to the page limitation, in this paper, we only present the detailed simulation result of the straight layout in Table 1. The overall comparison of the simulation results of the three layouts is shown in Table 2.

The model thus is based upon the all available data from the company, experiential estimation identified from the literature.

From the results of the simulated design model set out in Table 1, it is clear that the distribution of operation of the parts and the machines is not completely well-balanced. Compared with the operation of bore hole in the second line, the machine productivity, labor productivity and block time are much too high in the operation of bore hole in the first line. This situation causes insufficient supplies of semi products to the first production line and may thereby lead to the insufficient work loading of other production line operators, who are waiting for the delivery of products from work-stations further back down the line.

Table 1 The results of the simulation of the existing straight assembly line design

Operation of first line	Machine productivity (%)	Labor productivity (%)	block time (minutes)
Top hole drill	66.90	73.55	0.00
Melt	64.61	70.56	4.59
Side hole drill	66.02	73.53	9.40
Holder rivet	67.60	70.61	8.32
Bore hole	83.38	90.90	305.40
Tapping	41.30	44.69	3.22
Part rivet	47.33	51.55	4.51
Glue solidify	52.33	56.28	7.61
Measurement	53.19	59.25	11.15
Cleanup	79.07	82.42	20.60
Operation of second line	**Machine productivity (%)**	**Labor productivity (%)**	**block time (minutes)**
Top hole drill	56.69	61.51	0.00
Melt	56.33	61.63	4.11
Side hole drill	54.21	60.97	1.32
Holder rivet	29.16	34.83	0.00
Bore hole	27.87	32.04	1.63
Tapping	53.06	56.42	7.58
Part rivet	40.43	44.45	0.93
Glue solidify	52.47	56.31	3.62
Measurement	39.92	80.97	97.38
Cleanup	77.26	44.62	2.51

Table 2 The simulation results comparison of three layouts

	Straight -lines	U-shaped lines	Parallel U-shaped line
Product quality	292	291	290
Machine average productivity	52.9%	52.35%	58.06%
Labor number	60	50	42
Labor average productivity	60%	71%	85.85%
Max block time	305.4	309	45.27

Fig.5 The simulation results comparison of three layouts

From Table 2 and Fig. 5, it is shown that the best results are obtained in Parallel U-shaped line. Compared with the straight lines and U-shaped lines, in the parallel U-shaped line, the average machine productivity and labor productivity are improved and meanwhile, the labor number and block time are reduced. The experiments are based upon the fact that centralized management of labor and machine in the parallel U-shaped line. Also, with the decrease of the labor number and the centralized labor, the cost of the parallel U-shaped line is cheaper, the management difficulty is reduced and setting of the production line is more flexible.

The simulation experiments indicate that the best solution is not only related to production line layout, but also the balanced loading of equipment, decrease of labor number and appropriate use of management.

6. Conclusions

This paper presents the optimized layout design of the assembly line using the Witness simulation environment. With the same predefined processes input data in simulation, we compared three typical different layout simulation experiment results of straight line, U-shaped line and Parallel U-shaped line. From the analysis of simulation result data, a conclusion is drawn that parallel U-shaped line which meets the demand of decreasing the need for workforce and settling the bottlenecks problem is the best layout for this assembly line. Using concrete example, it has been demonstrated that the use of the Witness simulation environment-not only for suggestions designed to increase the affectivity of existing production runs, but also in the initial creation and design of production lines themselves is valid and effective.

Industrial layout is an important part of the entire production and processing chain. The transformation of the industrial layout represents a change in the rules of the game. Behind the industrial layout, there is a need to make corresponding changes in production management and personnel management. Otherwise, changing the soup without changing the medicine will not achieve the goal of improving production efficiency and drastically reducing production personnel.

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